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SOME NEW TYPES OF INSTRUMENTS USING SEMICONDUCTORS
(NEW APPLICATIONS OF THE HALL EFFECT)

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[Comment: The following report was submitted to the editors of *Zhurnal Tekhnicheskoy Fiziki* on [illegible] December 1955.

Numbers in parentheses refer to the author's bibliography appended. The figure mentioned in the text is also appended to the report.]

In the last few years increasingly frequent use has been made of the properties of some galvanomagnetic effects in semiconductors. Thus the effect of the variation of a semiconductor's resistance in a magnetic field and the Hall effect have been used as the basis for the creation of amplifiers, modulators, field indicators, multiplier units, etc. (1, 2, 3). All these uses can be divided into two groups: the first group includes, for example, amplifiers, which can be built without utilizing galvanomagnetic effects; the other group consists of apparatus facilitating the solution of radio engineering problems which defy solution by ordinary means. The purpose of this article is to remark on the potentialities of this nature exhibited by some devices employing the Hall effect.

Square-Law Detector

Hall voltage $V_x = RIB$, where R is the Hall constant, I is the current through the device, and B is the induction of the magnetic field.

Let $I = I_0 \cos\omega t$; $B = kI_0 \cos\omega t$.

Then $V_x = kRI_0^2 \cos^2\omega t = \frac{Rk}{2} I_0^2 + \frac{Rk}{2} I_0^2 \cos 2\omega t$.

Thus, the Hall electrodes yield a constant voltage $V = \frac{Rk}{2} I_0^2$ which is proportional to the square of the applied current. This is the case of the ideal square-law detector.

Ideal "Linear" Detector

If $B = B_0 \cos\omega t$, where B_0 = const, then $V = \frac{1}{2} B_0 R I_0$.

In this case the dc component of the Hall voltage depends linerly on the applied current. This is the case of the ideal "linear" detector. However, in this case the necessary condition is that B_0 = const.

Frequency Spectrum Analyzer

If the input current in case 2 is $\sum_{1} I_{01} \cos\omega_1 t$, then, by varying the frequency of the magnetic field we can selectively detect only that harmonic whose frequency at the given moment corresponds to the field frequency. In this case $V = \frac{1}{2} B_0 R I_{01}$.

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This type of detector, therefore, is simultaneously a spectrum analyzer with high resolving power. The essential feature of this detector is the fact that only one dc component is present in the output voltage, and that component is proportional only to one frequency in the spectrum being investigated. An experimental model of this apparatus was constructed by us from a monocrystal of germanium (ρ = 15 ohm · cm) in the form of a thin plate 0.0[illegible] x 0.6 x 1.2 cm which was placed in the gap of an ordinary E-shaped ferrite core. The input resistance of the model was 1,500 ohms. The experimental curves (see Figure 1) confirm the above-expressed considerations. On this detector it was possible to detect linearly signals of about 10 millivolts and display harmonics composing 0.01% of the amplitude of the whole voltage being investigated. A mirror galvanometer with a sensitivity of $1.5 \cdot 10^{-8}$ amperes scale division served as indicator. It can be shown that the voltage transfer factor in the Hall effect is

$$\frac{V_{x}}{V_{input}} = k = \frac{\mu B}{2 \cdot 10^{8}}$$

where μ is the mobility of current carriers in the substance in $\frac{cm^2}{v \cdot sec}$, and B is the induction in gauss. The critical field condition for the semiconductor is μB : 10^{8}, [illegible] the transfer factor can not be greater than unity. This is required by the law of conservation of energy.

Starting from this formula, one can calculate with a magnetic induction of one gauss and a current carrier mobility of 2,000 $\frac{cm^2}{v \cdot sec}$, that it is possible in the case of a harmonic analyzer to obtain a sensitivity of 0.1% if the minimum direct current in the Hall circuit is equal to 10^{-8} a, and the permissible dissipation in the device is one watt.

With a magnetic induction of [illegible] for devices made of germanium with a mobility of [illegible] $\frac{cm^2}{v \cdot sec}$ we obtain a sensitivity of about 0.0005%. For devices made of InSb with a mobility of 50,000 $\frac{cm^2}{v \cdot sec}$ the sensitivity will be ~ [illegible]

In the case of the linear detector, starting from the same formulas, we find that with an induction of one gauss and a mobility of 2,000 $\frac{cm^2}{v \cdot sec}$ we can obtain a dc Hall current of [illegible] a [illegible] ohm of input resistance if the input signal being detected is equal to one milli volt.

In the case of [illegible] gauss, the minimum detectable signal is equal to [illegible] microvolts. In the case of InSb with a mobility of [illegible] $\frac{cm^2}{v \cdot sec}$ the minimum signal will be equal to one microvolt.

The proposed devices have the following advantages.

1. There is no radio engineering device which can produce accurate square law conversion for a wide amplitude range. The Hall-effect detector makes this feasible.

2. At present there are no detectors capable of detecting linearly starting with very low signals. The Hall effect detector is capable of detecting linearly starting with several microvolts.

The resolving power and sensitivity of the analyzer based on the above-described principle is greater than that of existing spectrum analyzers. The range of analysis is extended from audio frequencies up to radio frequencies at which it is still possible to obtain strong magnetic fields. The apparatus can be of smaller size, but simpler and more convenient and reliable than ordinary analyzers.

All the above remarks once more emphasize the broad possibilities opened up by the use of semiconductors, whose employment in radio engineering is not limited to use in diodes or transistors.

[Appended figure follows.]

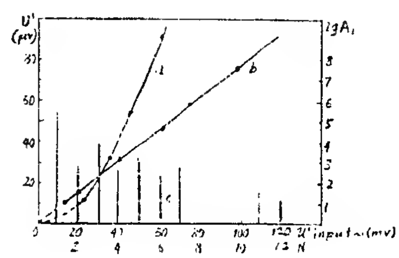

Fig 1. a -- characteristic of Hall-effect square-law detector; b -- characteristic of Hall-effect "linear" detector ($U = U_{input\sim}$); c -- 200-cps voltage spectrum of audio oscillator ZG-10 obtained with Hall-effect analyzer; Ai -- amplitude of i-th harmonic; N -- number of harmonic

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